

STUDIES ON IMPACT OF RELEASE OF LIQUID INDUSTRIAL WASTE FROM SODA ASH INDUSTRY IN THE NEARSHORE WATER OF NORTH GUJARAT

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The nearshore waters of Mithapur, Porbandar and Sutrapada received 18-100 mld (million litres per day) of wastewater from soda ash manufacturing industries either through point discharges (Mithapur, Porbandar) or through submarine outfall (Sutrapada). The impacts of these wastes on the water and sediment quality of the receiving waters are discussed.

Due to the density inhibited mixing the effluents tend to spread into a kilometre long milky white patch with high levels of pH, suspended solids and ammonia, along the shores on either side of the point of entry to the marine waters at Mithapur and Porbandar. Effective mixing and dispersion at Sutrapada on the contrary favoured marine environmental quality closely comparable to the predisposal baseline within the natural variability of coastal waters. The sediments wherever studied did not indicate any anthropogenic contamination. It is concluded that the pollution impact was localised and the marine life in the intertidal and subtidal regions of Mithapur and Porbandar is exposed to undesirable levels of ammonia.

INTRODUCTION

The abundant availability of lime stone and common salt - the major raw materials required for the manufacture of soda ash, in the coastal belt of North Gujarat has resulted in the establishment of soda ash manufacturing industries at Mithapur, Porbandar and Sutrapada. Over 90 per cent of the production of soda ash in India is achieved through these industries.

While the plants at Mithapur and Porbandar are operational for over 2 decades, the one at Sutrapada began production about 2 years back.

The industries with the production capacities between 1000-1500 tonnes of soda ash per day, generate 5-18 mld of process effluents which are released in the coastal water through point discharges. In addition, the plants also use 100-200 mld of seawater as coolant which in some cases, is used for diluting the process effluents or released through separate pipeline. The studies reported in this paper were undertaken to assess the impact of wastewater release on the marine environment and to establish the baseline for future comparisons.

MATERIALS AND METHODS

The coastal waters of Mithapur, Porbandar and Sutrapada were sampled at locations marked in Figure 1. The stations M_1 , M_5 , M_6 , M_7 , P_4 and P_6 were operated diurnally during premonsoon (March-April 81) and postmonsoon (December, 81-January, 82). The location S_5 was sampled diurnally twice a month from May 84 to January 85. The remaining stations were sampled during flood and ebb tides to have an overall picture of the study areas. In addition sampling along the length of the shores was also undertaken during December 1981 at Mithapur and March 1981 at Porbandar. The monitoring at the three study sites was again repeated during January-February 1990 to delineate changes if any in the environmental quality. The data pertaining to 1990 discussed in this paper is taken from the NIO Report (NIO, 1990).

A clean polyethylene bucket was used for surface sampling while Niskin sampler was used for obtaining samples one meter above the bed sediments.

Salinity, dissolved oxygen, PO_4^{3-} -P, NO_3^- -N, NO_2^- -N and NH_4^+ -N were analysed by using standard procedures (Grasshoff, 1976). For the determination of suspended solids, a known volume of water was filtered through preweighed 0.45μ Sartorius membrane filter paper which was weighed again after drying. BOD was determined by direct unseeded method (Martin, 1972). Heavy metals in the filtered and acidified samples were

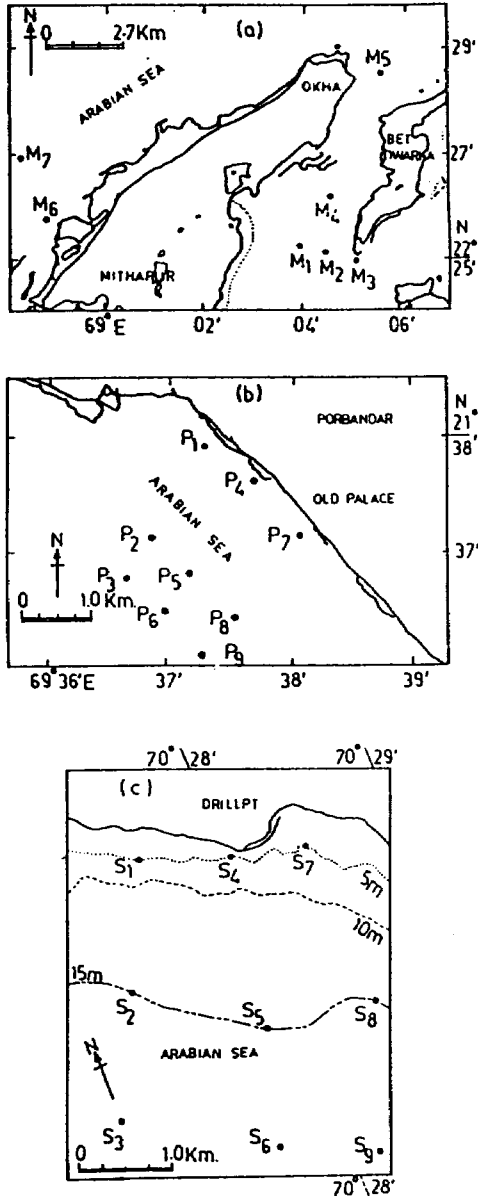


Fig. 1 Locations of sampling stations at (a) Mithapur, (b) Porbandar, and (c) Sutrapada.

determined by flame AAS (Hilger Watt Atomspék H-1550) after preconcentration by APDC-MIBK solvent extraction and back extraction in dilute acid (Grasshoff, 1976). The method developed by Hulthe *et al.* was modified and applied for the determination of B (Narvekar, 1979). Propionic anhydride and oxalyl chloride available locally gave erroneous results. Hence, these were replaced by acetic anhydride and hydrochloric acid respectively. Acetone was also replaced by methyl isobutyl ketone to avoid uncertainties due to the evaporation of acetone. Ca and Mg were analysed following the procedure of Culkin and Cox (1966). Photometric titration with EGTA and Zincon Zn-EGTA indicator yielded the concentration of Ca while complexometric titration with EDTA and Eriochrome Black T indicator gave combined concentrations of Ca, Mg and Sr. Appropriate correction (Narvekar, 1979) for Sr calculated from the relation $[\text{Sr (mg/kg)} = 0.42 \times \text{chlorinity}]$ and for a systematic overestimate of about 1 per cent in the titration end point were also applied.

The sediments obtained by using van Veen grab were analysed for Cr, Mn, Fe, Co, Ni, Cu, Zn, Pb and Al by flame AAS following a common and single digestion procedure of Buckley and Cranston (1971).

RESULTS AND DISCUSSION

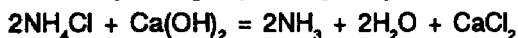
General description of study area

The Saurashtra coast displays variegated geomorphic features all along and is characterised by numerous cliffs, small islands, tidal flats, deposits of littoral concrete in rocky beaches, sandy beaches, bars, dunes and coral formations. The Deccan Traps, forming the mainland of Saurashtra is exposed over vast areas. Quarternary formations consisting of Milliolitic limestone and alluvium form the narrow coastal strip. The solubility of limestone in water is responsible for creating Karst topography where limestone is exposed. Rock surface is pock-marked with various sizes of circular holes, cavities and large size covers through which precipitation percolates to the water table. Normal wind system in the area is basically seasonal with reversal of directions. High wind speeds for a greater percentage of time occur during May to July. Predominant direction of these winds is between west and south west. The annual rainfall varies from 700

mm at Veraval to 450 mm at Okha with 80 per cent precipitation occurring during June-August. The tides in the region are mixed semidiurnal type with a large diurnal inequality. The mean high water spring increases from 2.09 m at Veraval to 3.47 m at Okha; the respective increase during neap is from 1.82 m at Veraval to 2.96 m at Okha.

Soda ash manufacturing process and effluent characteristics

Chemically purified and clarified saturated brine is ammoniated and then carbonated to precipitate sodium bicarbonate in a slurry form. The slurry is filtered and the crude sodium bicarbonate cake is washed and calcined to produce soda ash. The ammonia is recovered from the filtrate (ammonium chloride) for recycling by treatment with lime and steam distillation. Carbon dioxide and lime required in the process are obtained by burning limestone and coke in shaft kilns. The overall chemical reactions are as follows:



Brine refinery sludge and ammonia still effluents are the major wastewater streams in this process. Typical characteristics of these wastewater streams are given in Table 1. It is evident that the wastewater is expected to contain high levels of inorganic suspended solids, high pH and variable levels of ammonia.

Mithapur

An industry manufacturing soda ash, sodium carbonate, caustic soda, benzene hexachloride, vacuum salt and bromine generated around 18 mld of highly alkaline (pH > 12) process waste. The wastewater which contained around 150 g/l of suspended solids and 25 mg/l of ammonia nitrogen was released through a point discharge on the marshy land above the high water line. The solids mainly consisting of calcium carbonate, calcium sulfate, magnesium hydroxide and silica largely settled in the marshy zone between the release location and the intertidal area and piled in heaps along

Table 1: Characteristics of major wastewater streams in the manufacture of soda ash (Dry liming technology)

| Parameter | Brine refinery sludge | Ammonia still effluent |
|---------------------------------|-----------------------|------------------------|
| Temperature (°C) | Ambient | 80 - 90 |
| Sp. gravity | 1.05 - 1.15 | 1.10 - 1.13 |
| Solids (per cent) | 10 - 12 | 4 - 5 |
| CaCO ₃ | 50 - 65 | 30 - 40 |
| CaO | - | 10 - 15 |
| CaSO ₄ | 2 - 5 | 5 - 10 |
| Mg(OH) ₂ | 10 - 30 | 0.5 - 2 |
| SiO ₂ | 2 - 6 | 3 - 10 |
| Clear liquid (g/l) | | |
| CaCO ₃ | 0.0 - 0.15 | 0.0 - 0.15 |
| CaSO ₄ | 2.0 - 5.0 | 1.0 - 3.0 |
| Na ₂ SO ₄ | 2.0 - 6.0 | - |
| NaCl | 50 - 100 | 50 - 60 |
| CaCl ₂ | - | 100 - 120 |
| Ammonia | - | 0.1 - 3 |

the shores. The liquid waste devoid of much of its suspended matter entered the Gulf through irregular intertidal channels. The raw effluent was quite toxic and even at 20 per cent concentration the fishes did not survive for more than 15 min; LC₅₀ for 96 h was obtained at a concentration of 5.5 per cent (Nair *et al.*, 1987).

The seawater required for cooling was drawn from the Arabian Sea and the heated effluents were released through a point discharge away from the intake location.

The mean values of diurnal observations at locations M₁, M₅, M₆ and M₇ are given in Table 2. As the results of flood and ebb tide at other locations did not vary appreciably, these were not included in the Table. Although the region was devoid of any freshwater inflow, diurnal variation in salinity (Figure 2) occurred from 36.8‰ at the flood tide to 38.8‰ around the ebb. This increase in salinity near the shore appeared to be due to the percolation of high salinity water from the intertidal areas exposed during low tide and the highly saline wastewater. The latter was contributing

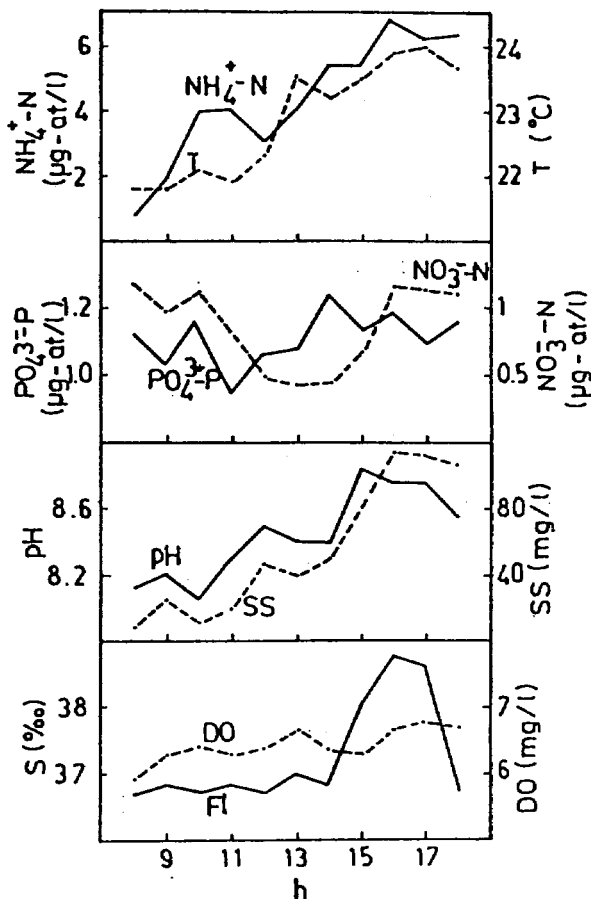


Fig. 2 Temporal variation of some physico-chemical parameters at station M1 on 23.12.1981.

perceptibly at station M₁, because increase in salinity was also associated with the corresponding increase in pH, suspended solids and NH₄⁺-N. The salinity, pH and NH₄⁺-N on the contrary varied only marginally at other locations in the area. Thus for instance the salinity varied from 35.3 to 36.9‰, pH from 7.9 to 8.1 and NH₄⁺-N from 0 to 3 µg-at/l at stations M₂ to M₅. Hence, the influence of wastewater on the water quality was largely restricted to nearshore regions around the wastewater release location. Comparison of 1981 results with more recent observations (NIO, 1990) revealed (Table 2) that the water quality has remained more or less steady over the years.

Table 2: Water quality of coastal water of Mithapur

| Parameter | M ₁ | | | M ₅ | | | M ₆ | | | M ₇ | | |
|--|----------------|------|------|----------------|------|------|----------------|------|------|----------------|------|------|
| | M 81 | D 81 | F 90 | N 81 | D 81 | F 90 | A 81 | F 90 | A 81 | F 90 | A 81 | F 90 |
| Temperature (°C) | 26.1 | 21.9 | 23.9 | 26.6 | 22.4 | 23.5 | 25.9 | 23.9 | 26.4 | 24.1 | | |
| pH | 7.9 | 8.1 | 8.2 | 8.0 | 8.1 | 8.1 | 8.2 | 8.1 | 8.2 | 8.2 | | |
| Suspended solids (mg/l) | 21 | 10 | 12 | 8 | 23 | 37 | 30 | 33 | 8 | 71 | | |
| Salinity (‰) | 36.3 | 36.2 | 36.2 | 36.2 | 35.9 | 36.0 | 36.1 | 36.5 | 36.0 | 36.5 | | |
| DO (mg/l) | 6.5 | 7.5 | 7.7 | 6.6 | 7.3 | 7.0 | 7.4 | 7.1 | 6.5 | 6.6 | | |
| BOD (mg/l) | 1.8 | 2.9 | 1.5 | 1.3 | - | 0.6 | 1.5 | 1.9 | 0.8 | 1.1 | | |
| PO ₄ -P (µg-at/l) | 1.1 | 1.1 | 1.0 | 1.1 | 1.8 | 1.2 | 0.8 | 1.8 | 1.1 | 1.5 | | |
| NO ₃ -N (µg-at/l) | 0.4 | 0.6 | 1.1 | 0.4 | 0.9 | 1.9 | 1.1 | 1.7 | 1.3 | 1.2 | | |
| NO ₂ -N (µg-at/l) | 0.3 | 0.2 | 0.2 | 0.6 | 0.4 | 0.3 | 0.3 | 0.3 | 1.7 | 0.3 | | |
| NH ₄ ⁺ -N (µg-at/l) | 4.2 | 0.8 | 0.2 | 2.2 | 1.5 | 0.5 | 0.3 | 0.5 | 0.5 | 0.3 | | |
| Chlorophyll (mg/m ³) | 9.5 | 10 | 0.9 | 9.5 | 2.9 | 0.9 | 11.5 | 1.4 | 28 | 2.6 | | |
| Carotenoids (m.SPU/m ³) | 1.5 | 3.8 | - | 7 | 3.2 | - | 1.8 | - | 4.5 | - | | |
| Zooplankton biomass (ml/100 m ³) | 6.9 | 0.4 | 1.2 | 2 | 0.1 | 1.2 | 1.3 | 6.2 | 1.8 | 7.7 | | |

M - March; A - April; D - December; F - February

Because of its high density the effluent flowing into the seawater did not mix effectively and spread along the shore as a milky white patch. The white colour of the patch was associated with the high content of suspended solids containing calcium carbonate, calcium sulphate, magnesium hydroxide and silica. To ascertain the spread of wastewater along the coast, shore sampling was undertaken every 200 m from the wastewater release location. From the results given in Figure 3 it is clear that the wastewater formed a band along the shore with a length of about 1 km within which the salinity, pH, $\text{NH}_4^+\text{-N}$ and suspended solids were distinctly higher than at other stations.

The behaviour of Ca, Mg and B was also investigated particularly because the wastewater had high concentration of calcium chloride (Table 1). Ca, Mg and B are conservative in seawater and their ratios with chlorinity are more or less constant. The samples having chlorinity below 20‰ resulted in Ca/Cl ratios varying in a narrow range of 0.0213 to 0.0225. However, the samples with higher chlorinity, particularly from station M₁ and those of

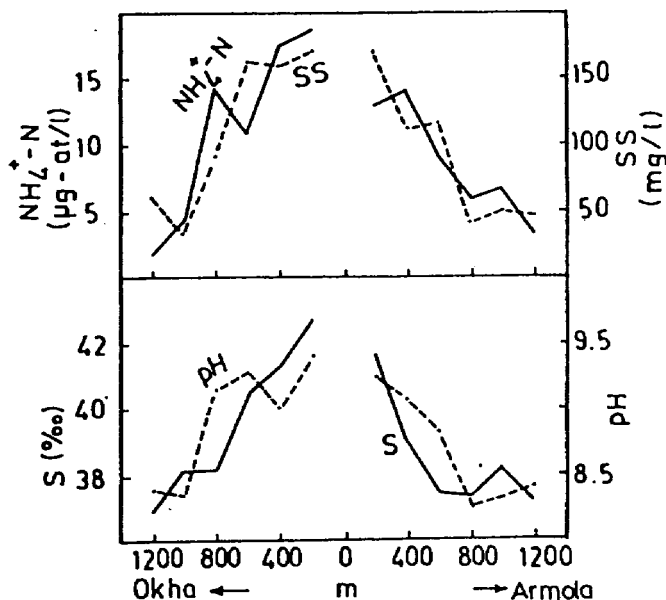


Fig. 3 Nearshore variation in salinity, pH, $\text{NH}_4^+\text{-N}$ and suspended solids in the vicinity of wastewater entry location at Mithapur on 29.12.1981.

shore sampling revealed abnormal Ca/Cl ratios (0.0229 to 0.0285) suggesting that the calcium released through the wastewater remained in solution upsetting the Ca/Cl ratio. The mean ratios of B and Mg to chlorinity (0.23 ± 0.008 and 0.066 ± 0.0004 respectively) were however close to the seawater ratios reported for the coastal water of Gujarat (Narvekar and Zingde, 1987).

The impact of the fluxes of the dissolved trace metals through wastewater on the water quality was not evident (Table 3). At the high pH associated with the effluent these metals were expected to be in particulate form and because of the alkaline pH of seawater their mobilization was less likely. These particulate metals would be transported to the bed sediments with the settling suspended solids.

The sediment in the region was mainly made up of sand and hence was not analysed for trace metals.

The biological characteristics (Nair *et al.*, 1987) indicated fairly high productivity in terms of macrobenthos and phytoplankton pigment concentration, although the region sustained low standing stock of zooplankton. The overall biological productivity of plankton and macrobenthos revealed 30 to 90 per cent reduction from the premonsoon to the postmonsoon period. The decline in standing stock of plankton and benthos coincided with the peak fishing season and there was no evidence of any gross impact of release of wastewater on the biota.

Porbandar

An integrated complex manufacturing soda ash and related products generated about 6 mld of process waste which was diluted by about 15 times with the spent cooling seawater and released to the nearshore water through an open drain about 1.5 km away from the seawater intake location. The wastewater contained high suspended load (2.5 g/l) mostly inorganic in nature, high pH (9-10) and high ammonia nitrogen (5-60 mg/l).

Similar to the behaviour in the coastal waters of Mithapur, the wastewater had tendency to spread along the shore as a milky white patch as evident

Table 3 : Metals in water ($\mu\text{g/l}$) and sediments (values in parentheses; ppm dry wt. except for Fe and Al for which values are given in percentage) along the Saurashtra coast

| | Cr | Mn | Fe | Co | Ni | Cu | Zn | Pb | Al |
|-----------|----------------|-------|-------|------|------|------|-------|------|-------|
| Mithapur | M ₁ | - | 17 | ND | ND | 4 | 48 | - | - |
| | M ₆ | - | 14 | ND | ND | 8 | 13 | - | - |
| Porbandar | P ₄ | - | 43 | ND | ND | 5 | 32 | - | - |
| | P ₆ | (28) | (432) | (12) | (18) | (28) | (56) | (16) | (1.8) |
| Sutrapada | S ₆ | - | 40 | ND | ND | 13 | 18 | - | - |
| | S ₆ | (106) | (653) | (26) | (67) | (78) | (110) | (3) | (4.8) |
| Sutrapada | S ₆ | - | 13 | ND | ND | 4 | 15 | 3 | - |
| | S ₆ | (113) | (820) | (25) | (73) | (71) | (121) | (5) | (7.7) |
| Sutrapada | S ₆ | - | 11 | ND | ND | 12 | 8 | 2 | - |
| | S ₆ | (126) | (863) | (32) | (97) | (85) | (136) | (5) | (7.9) |

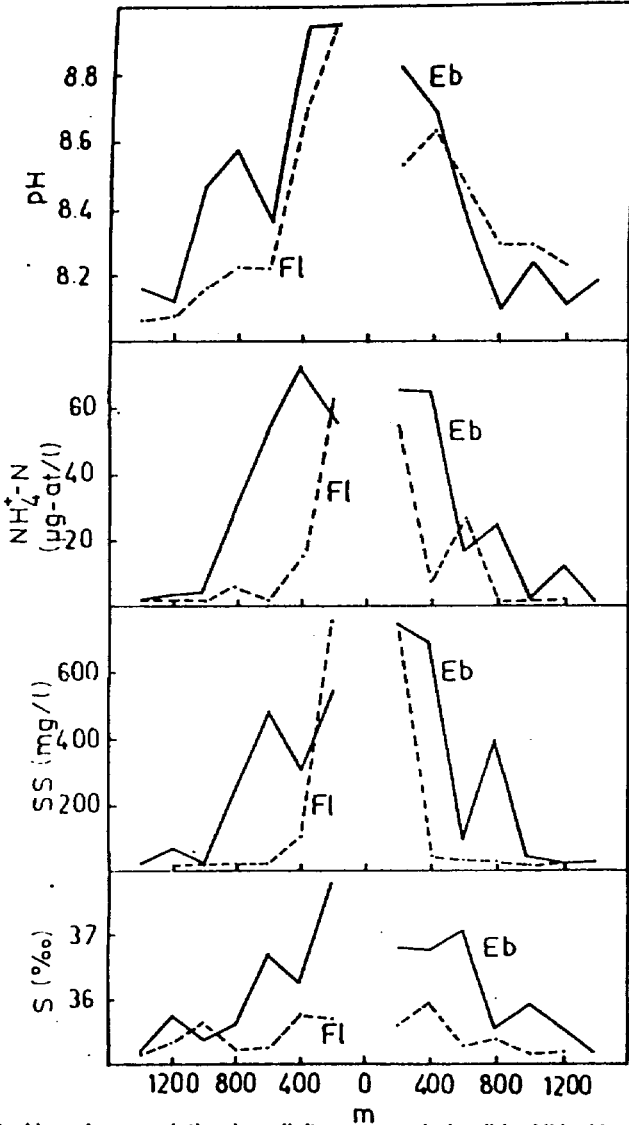


Fig. 4 Nearshore variation in salinity, suspended solids, $\text{NH}_4^+\text{-N}$ and pH during flood and ebb tides in the vicinity of the wastewater entry location at Porbandar on 25.3.1981.

from Figure 4. This spread was upto about a km on either side of the point of entry of wastewater during ebb tide and decreased during flood tide.

The salinity gradient between the surface and bottom (Figure 5) was often above 0.5‰ at station P₄ (closest to the wastewater release location). Such a gradient was absent or weak at other locations (Figure 6) except on a few occasions. Association of high suspended solids, high NH₄⁺-N and high pH with the bottom water at station P₄ (Figure 5) suggested that the wastewater while spreading along the shore also diffused away from the coast preferentially along the bottom due to higher specific gravity (1.04) as compared to that of the seawater. Abnormal values of pH and NH₄⁺-N were also sometimes observed at stations P₁, P₇ and P₅.

The effluent transported 3 x 10⁶ kg/day of NH₄⁺-N to the coastal waters. The toxicity of ammonium salts to aquatic life has been shown to be strongly dependent on the pH in a manner that is consistent with un-ionised ammonia (NH₃) which is the most lethal fraction (Whitfield, 1974).

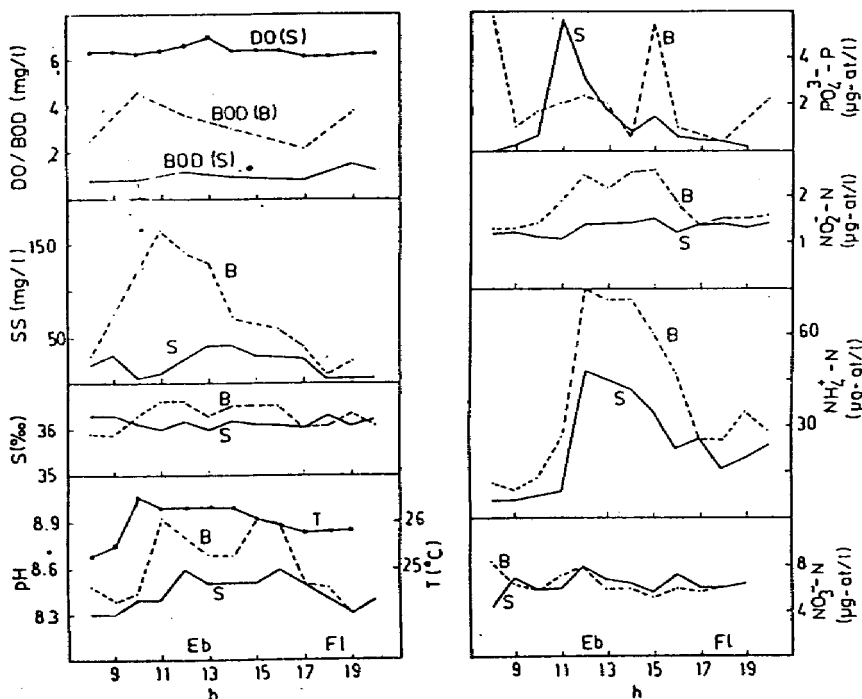
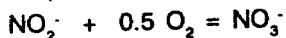
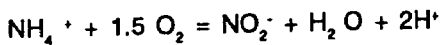


Fig. 5 Temporal variation (S - Surface, B - Bottom) of some physico-chemical parameters at station P₄ on 14.3.1981.

At the pH of receiving water (8.5-8.9) it was expected that 5 to 30 per cent of ammonia would be in the unionised form. At the highest concentration of 75 $\mu\text{g} - \text{at/l}$ of $\text{NH}_4^+ - \text{N}$ observed at station P_4 , around 0.3 mg/l unionised $\text{NH}_3 - \text{N}$ would be present. However, at other locations the maximum concentration of unionised $\text{NH}_3 - \text{N}$ would be as low as 0.01 mg/l. As discussed above, the wastewater tends to spread along the shore forming a white patch. At the pH encountered around the wastewater release location (Figure 4) the concentration of unionised $\text{NH}_3 - \text{N}$ would be varying in 0.1 to 0.3 mg/l range. Although short term exposures to concentrations of unionised ammonia below 0.15 mg/l may not kill a significant proportion of a fish population, it may however exert an adverse physiological or histopathological effect. It is considered that the concentration of unionised ammonia should not exceed 0.02 mg/l for prolonged exposures (Whitfield, 1974).

Marine life particularly in the intertidal and the subtidal regions would therefore be subjected to prolonged exposure to undesirable levels of unionised ammonia. The impact, however, would be localised to nearshore area only and would not affect the fishery of the region.

The NH_3 and NH_4^+ entering the marine waters would be removed through various processes. The NH_4^+ is oxidised to NO_3^- via NO_2^- in estuaries and shallow marine systems (Henriksen and Kemp, 1988) in two steps:



Several intermediate compounds (e.g. hydroxylamine) and byproducts (e.g. nitrous oxide) of nitrification have been identified and may accumulate under certain conditions. *Nitrosomonas* spp and *Nitrobacter* spp are the principal organisms responsible for the two steps. NO_2^- produced in nitrification may also be used as an electron-acceptor for its reduction to gaseous forms (N_2 or N_2O) under certain conditions. Nitrification in the water column off Porbandar appeared to be limited as evident from the relatively low levels of $\text{NO}_3^- - \text{N}$ and $\text{NO}_2^- - \text{N}$ (Table 4) and higher concentrations of $\text{NH}_4^+ - \text{N}$ at station P_4 .

Table 4: Water quality of coastal water of Porbandar

| | P ₄ | | | P ₆ | | |
|---|----------------|------|------|----------------|------|------|
| | M 81 | J 82 | F 90 | M 81 | J 82 | F 90 |
| Temperature (°C) | 26.1 | 22.9 | 23.4 | 24.9 | 22.5 | 24.1 |
| pH | 8.5 | 8.2 | 8.3 | 8.0 | 8.0 | 8.2 |
| Suspended solids (mg/l) | 95 | 49 | 9 | 12 | 9 | 10 |
| Salinity (‰) | 36.2 | 35.2 | 35.7 | 36.5 | 35.1 | 35.9 |
| DO (mg/l) | 6.5 | 7.2 | 7.3 | 6.2 | 6.7 | 6.7 |
| BOD (mg/l) | 2.2 | 1.5 | 1.7 | 1.7 | 2.1 | 0.8 |
| PO ₄ ³⁻ -P (µg-at/l) | 2.0 | 1.3 | 0.4 | 1.8 | 1.5 | 0.5 |
| NO ₃ ⁻ -N (µg-at/l) | 6.7 | 2.4 | 0.8 | 1.5 | 1.0 | 0.4 |
| NO ₂ ⁻ -N (µg-at/l) | 1.7 | 0.5 | 0.1 | 0.5 | 1.0 | 0.2 |
| NH ₄ ⁺ -N (µg-at/l) | 30 | 16 | 0.1 | 1.2 | 2.3 | 0.6 |
| Chlorophyll <i>a</i> (mg/m ³) | 39 | 14 | 3.4 | 15 | 7 | 1.8 |
| Phaeophytin (mg/m ³) | - | - | 1.1 | - | - | 1.1 |
| Zooplankton biomass (m ^l /100 m ³) | 6.2 | 35 | 9.5 | 6.3 | 44 | 52 |

J - January; F - February; M - March

The NH₄⁺ in marine water would be largely utilized for plankton production. It has been shown that the inshore primary production is for the greater part, based on ammonium and urea utilization (McCarthy *et al.*, 1977). In agreement with the laboratory findings a number of investigations of nearshore areas have shown that nitrate uptake even at high nitrate concentrations is largely inhibited by ammonium concentrations greater than about 1 µg - at/l. The high phytoplankton productivity in the nearshore water of Porbandar (Jiyalal Ram *et al.*, 1988) would be then due to the availability of high ammonium concentrations. A small fraction of the ammonium would also be adsorbed to the particulate suspended solids and transported to the bed sediments (Boatman and Murray, 1982).

The levels of trace metals in water were low (Table 3) and did not reveal any impact of release of wastewater. However, it must be remembered that assessment of metal pollution through water analyses frequently gives rise to difficulties because of low levels and their rapid removal through hydrolysis, adsorption on suspended particulate matter etc. resulting in their transfer to the bed sediments. Hence, establishment of their levels in

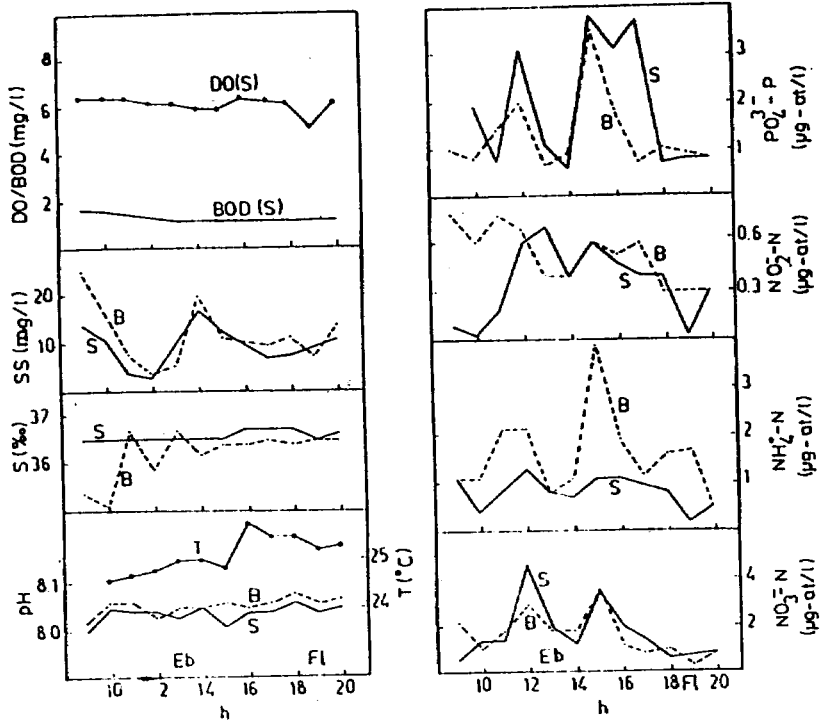


Fig. 6 Temporal variation (S - Surface, B - bottom) of same physico-chemical parameters at station P₆ on 15.3.1981.

sediments play a key role in assessing the metal pollution in marine system. The concentrations of some metals in bulk sediment from stations P₄ and P₆ are given in Table 3. Comparison of these levels with those at stations S₅ and S₆ unaffected by any wastewater release, revealed that there was no gross contamination of sediment at Porbandar. It is evident from the Table 3 that the trace metals except for Pb and Co increased with the increase in Al percentage. Texturally these sediments were silty clay or clayey silt type. Uniformly high concentrations of Al associated with these sediments indicated their terrigenous nature. This was also supported by good correlation exceeding 0.85 between Al and other metals except for Fe and Pb. The presence of montmorillonite and illite in larger percentages in the sediments of Saurashtra region is favourable for the adsorption of trace metals from water and their incorporation into the sediment (Murty *et al.*, 1980). It is evident from Table 3 that at station P₄ the levels of metals were markedly low except for Pb. Visual examination

Table 5: Water quality of coastal water of Sutrapada

| Parameter | Pr M 84 | Po M 84 | F 90 |
|--|---------|---------|------|
| Temperature (°C) | 27.5 | 26.1 | 24.9 |
| pH | 7.8 | 8.2 | 8.3 |
| Suspended solids (mg/l) | 54 | 31 | 20 |
| Salinity (‰) | 36.5 | 35.4 | 35.1 |
| DO (mg/l) | 4.4 | 5.6 | 7.0 |
| BOD (mg/l) | - | 2.3 | 1.5 |
| PO ₄ ³⁻ -P (µg-at/l) | 0.8 | 1.1 | 0.8 |
| NO ₃ ⁻ -N (µg-at/l) | 3.7 | 12 | 1.9 |
| NO ₂ ⁻ -N (µg-at/l) | 0.8 | 0.7 | 0.5 |
| NH ₄ ⁺ -N (µg-at/l) | 3.8 | 0.5 | 0.8 |
| Chlorophyll <i>a</i> (mg/m ³) | - | 0.7 | 4.0 |
| Phaeophytin (mg/m ³) | - | 0.8 | 1.2 |
| Zooplankton biomass (ml/100 m ³) | - | 169 | 29.4 |

Pr M - Premonsoon; Po M - Postmonsoon; F - February

of this sediment indicated substantial occurrence of fine white particles mixed with silty clay. These white particles must have been associated with the suspended load in the wastewater (Table 1) and were expected to be largely CaCO₃. The CaCO₃ content of this sediment was found to be more than 60 per cent as against expected 20-30 per cent (Murty *et al.*, 1980). Hence the sediment at station P₁ was considerably diluted with suspended solids from the wastewater which resulted in lower levels of metals.

Phytoplankton distribution in the coastal waters of Porbandar has been studied. Phytoplankton pigments and populations indicated wide variations. Higher cell counts and lower diversity of species encountered in the nearshore waters has been attributed to the localised impact of wastewater (Jiyalal Ram *et al.*, 1988).

Sutrapada

Detailed marine environmental quality of coastal water of Sutrapada was studied prior to the establishment of the soda ash industry. The coastal waters exhibited moderate seasonal variations in water temperature

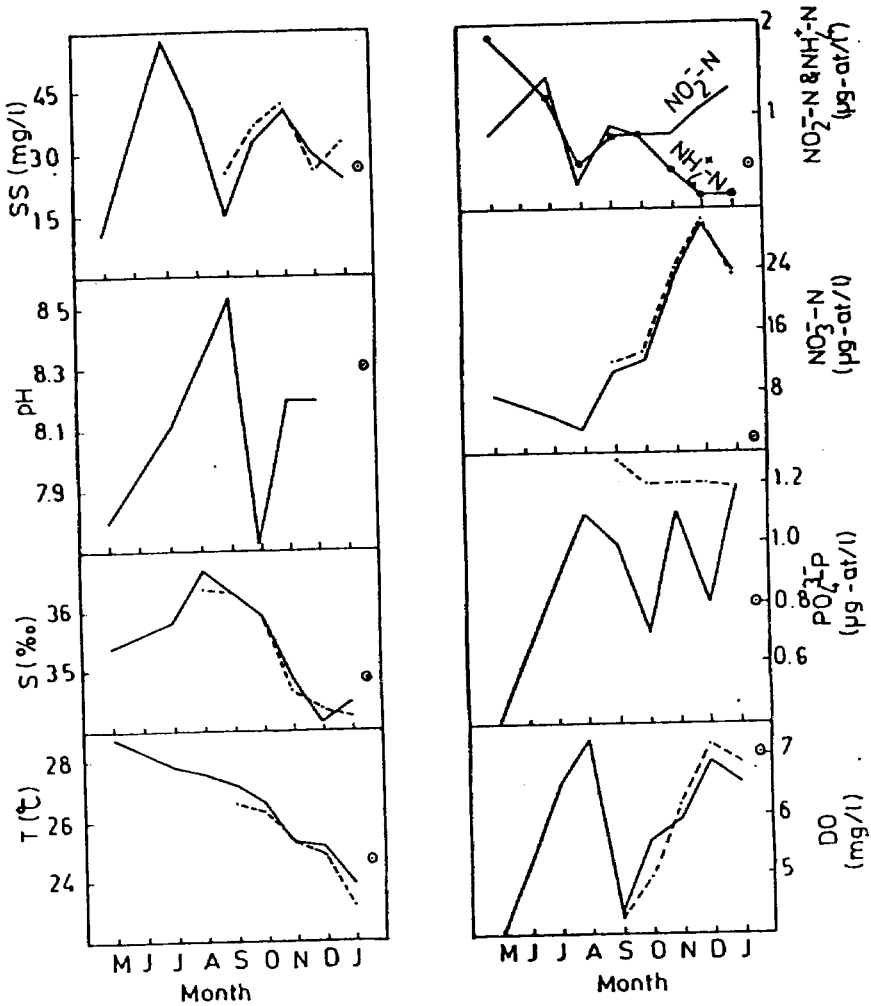


Fig. 7. Monthly variation of some physico-chemical parameters at station S₅ (Surace —, Bottom - - -) during 1984-85 and February 1990 (Shown by circle).

and salinity (Figure 7). The waterbody was generally well-mixed vertically though the salinity occasionally varied from surface to bottom by about 2‰.

The salinity of 35.5‰ during May increased to 36.6‰ during August followed by a systematic decrease to 34.2‰ during December. This

pattern of salinity variation was unexpected in view of the adjoining arid land mass. This behaviour was perhaps associated with the flow pattern off Sutrapada coast (NIO, 1985). The influence of reversing tidal currents associated with the high tidal regimes in the Gulf of Cambay is perceptible at least upto the north-west of Diu Point. These effects induced by the circulation in the Gulf of Cambay decrease considerably further north. Sutrapada-Veraval region appears to be a transition zone where the unidirectional flow was dominant in conjunction with weak influence of reversing tidal currents. The tidal flow which was more or less parallel to the coast showed a net southerly drift which was pronounced during the premonsoon and monsoon facilitating transport of high saline, low nutrient water from further north to Sutrapada. The circulation pattern undergoes significant changes during the late monsoon and postmonsoon with prominent northerly drift which is most dominant during November-December. Perhaps under the influence of the northerly drift the low saline, high nitrate water mass from the Gulf of Cambay moves upto Sutrapada resulting in decrease in salinity and increase in nitrate levels from August to December. Although the water of the Gulf of Cambay has high suspended load, the particulate matter being mainly of silt-clay origin would settle and largely removed from the water column.

On the basis of detailed hydrodynamic studies the industry began releasing treated wastewater beyond 4 m depth contour from 1986 onwards. The results of 1990 monitoring marked with circles on Figure 7 indicated that the water quality had remained largely unaltered within the natural variability expected for coastal waters.

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